Numerical Weather Prediction

Observing System Experiments using the Met Office three-dimensional variational assimilation scheme

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ABSTRACT

An Observing System Experiment is carried out using the Met Office three-dimensional variational data assimilation scheme (3D-Var) and global forecast model. The experiment investigates the impact on forecasts of up to 6-days of denying whole observing systems (radiosonde, satellite, aircraft and surface). A total of 60 forecasts from two 30-day periods - July 2001 and January 2002 - are verified.

The results show that overall all observing systems have a positive impact on mean forecast quality indicating that the Met Office 3D-Var system performs well.

The experiment also gives an estimate of the relative benefit that the different components of the Global Observing System are having on Met Office NWP forecasts. Results indicate:

- Satellite data have the largest positive impact of all observation types on forecasts in the southern hemisphere and have a significant positive impact in the tropics and northern hemisphere.
- Satellite radiance data have a larger impact than data from Atmospheric Motion Vectors (AMV) which have a measurable impact in the extra-tropics only when satellite radiance data are not present. The benefit of AMV data can be most clearly seen in the tropics.
- Surface data have a significant impact on surface pressure forecasts, but there may be some redundancy in the network for global Met Office NWP forecasts run at 90 km resolution.
- Radiosonde data are important for northern hemisphere forecasts and also have benefit in the tropics and southern hemisphere.
- Aircraft data play a relatively important role, particularly for short-range wind forecasts in the northern hemisphere and tropics.

The results from this experiment are in broad agreement with those from a similar experiment, using four-dimensional variational assimilation, carried out by ECMWF.

A further experiment investigates the impact of sub-components of the surface network (reports from land surface stations, ships and buoys). 30 forecasts from July 2001 are verified. The results from this experiment show that direct 'in-situ' observations of surface pressure have a large positive impact on NWP forecasts of mean sea level pressure. But removing whole sub-components of the surface network does not lead to a noticeable reduction in forecast quality.

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1. Introduction

The effective use of observations is essential for the production of NWP forecasts. It is thus important to carry out studies which assess the impact of the Global Observing System (GOS), or components of it. An effective way of doing this is by performing Observing System Experiments (OSEs). In an OSE, a continuous assimilation/forecast cycle is run under various observation-use scenarios and the results from the runs compared. Using this method, the impact of extra data obtained through special field campaigns can be assessed (e.g. Cardinalli 2000) or the impact of groups of observations on downstream regions investigated (e.g. Cress & Wergen 2001; Hirshberg et al. 2001). The relative benefit of whole observing systems can also be estimated (e.g. Zapotocny et al. 2002). The results from OSEs can give valuable guidance to observation network designers within organisations such as EUCOS[1] and WMO.

The results from OSEs are partly influenced by the distribution, frequency and quality of the observations used and partly by the effectiveness of the data assimilation system used in the experiments. Thus OSEs can also be used as a test of data assimilation techniques. A good way of assessing the overall effectiveness of a data assimilation method is to run an OSE as a global data denial trial. In such OSEs, whole observing systems are omitted and the impact on forecasts compared with a run that includes all observations. If the data assimilation system is working effectively, then it would be expected that the mean impact on forecasts of denying an observing system would be negative.

Such OSEs have been carried out at some NWP centres such as ECMWF (Bouttier & Kelly 2001; subsequently referred to as BK2001) who used a four-dimensional assimilation (4D-Var) scheme. The results presented in this paper are taken from a similar OSE carried out at the Met Office. This global data denial experiment, which investigates the impact of all observing systems, is the first such one to be carried out within the Met Office using three-dimensional variational assimilation (3D-Var). Two one-month periods of observations, from July 2001 and January 2002, were used in this experiment and sixty forecasts assessed. Future global data denial trials are planned following on from major forecast model or data assimilation upgrades.

2. Use of Observations

Maps showing typical distributions of observations of different types, that passed 'background' and 'buddy' quality control checks (Ingleby, 1992) and were assimilated by the Met Office model in a particular operational run, are given in Figure 1. Each dot on the maps represents the horizontal position of an observation that has passed quality control checks. Note that the dots may represent the position of a single level observation or profile.

It can be seen that a large coverage of upper-level radiance observations is available [Figure 1(a)]. The only consistent gaps in the coverage are over certain land areas where the modelling of surface emissivity is difficult. Atmospheric Motion Vectors

[1] EUCOS - EUMETNET Composite Observing System (see http://www.eucos.net/)

(AMVs) from geostationary satellites are used equatorward of 60º [Figure 1(b)]. Note that most observations are assigned to the two levels 850 and 250 hPa. Upper level profile reports from radiosondes, that provide direct measurements of wind, temperature and humidity, are widely but irregularly distributed over land areas [Figure 1(c)]. There are also a small number of observations taken from oceanic islands and ships. In-situ observations of surface parameters, taken from land stations, ships, oceanic drifting buoys and moored buoys, are widely distributed throughout the globe [Figure 1(d)]. Measurements from aircraft provide observations at flight levels. An increasing number of aircraft now take observations during ascent and descent thus providing profile information near airports [Figure 1(e)]. Currently, the density of aircraft reports over North America and Europe is considered too high to be effectively assimilated. Consequently aircraft reports are thinned before assimilation to a density of one report in each 100 km box, within a 50 hPa pressure band, and within a two hour time period (Dalby & Berney, 1999).

In Figures 1(d) and 1(e) 'BOGUS and 'TCBOGUS' observations are also plotted. 'BOGUS' observations are created manually by forecasters and are usually based upon a subjective analysis of satellite imagery. 'TCBOGUS' observations are generated objectively from tropical advisory messages (Heming et al, 1995).

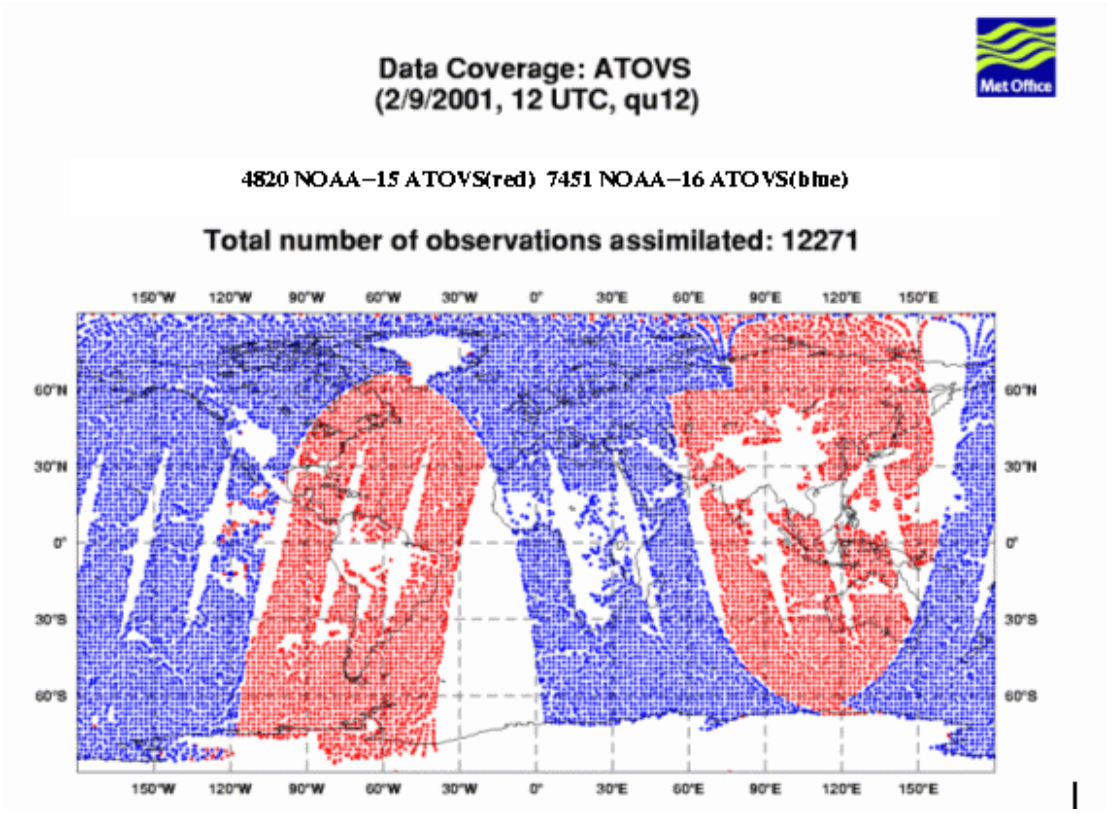
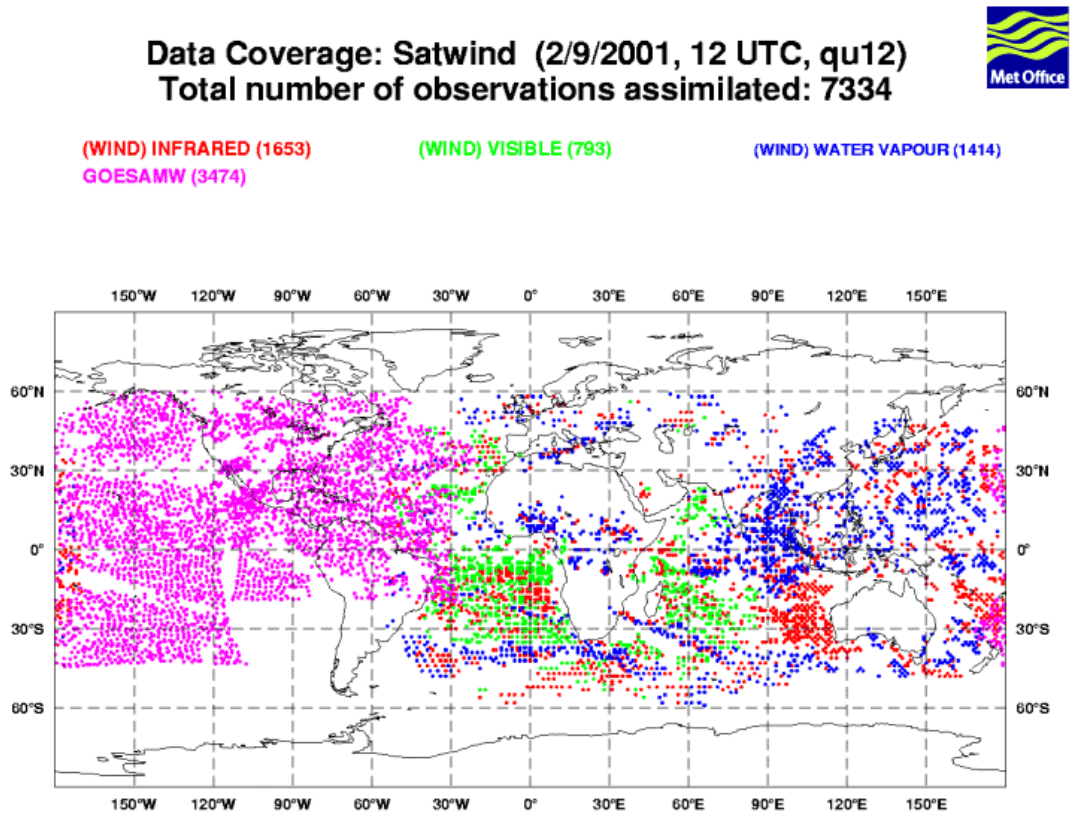


Figure 1(a)



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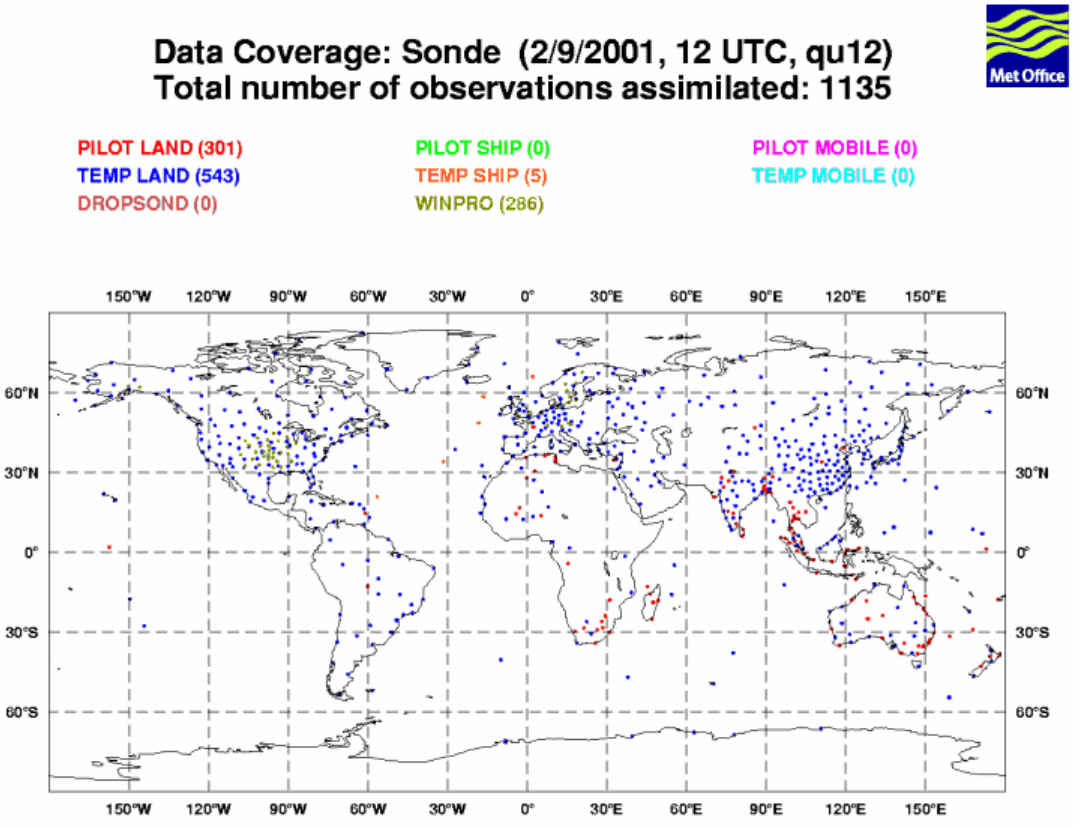

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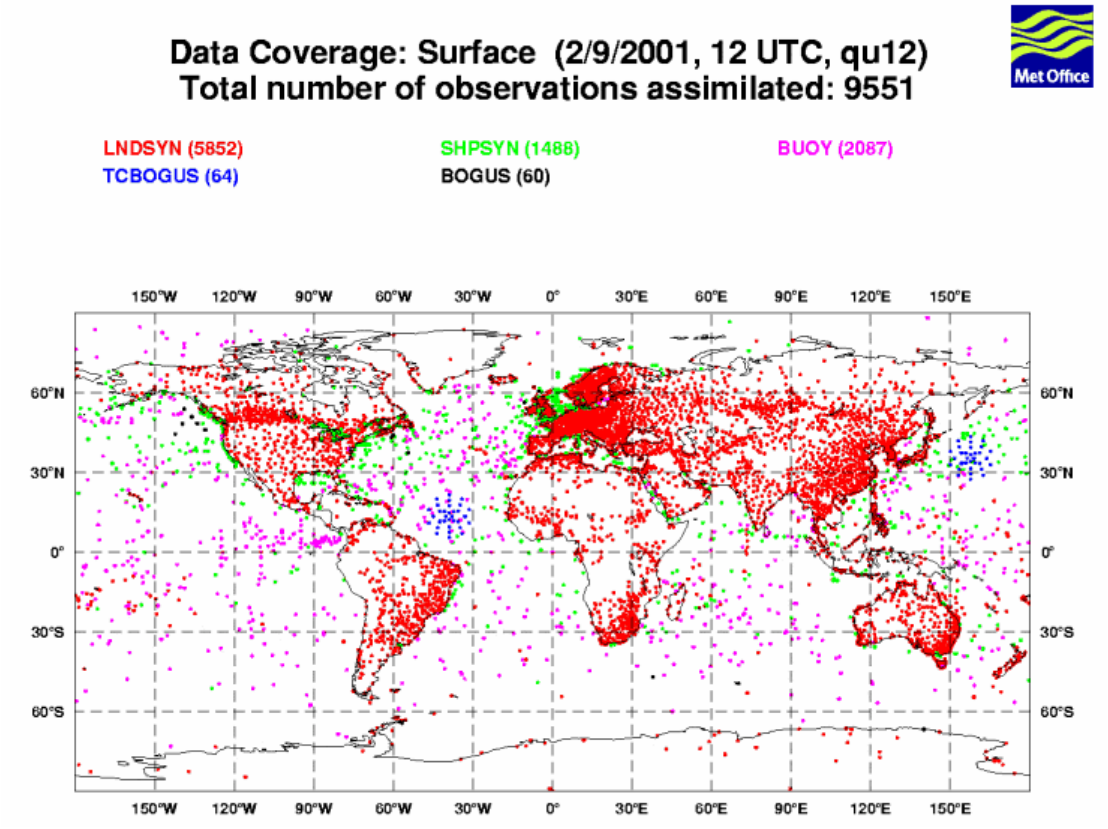

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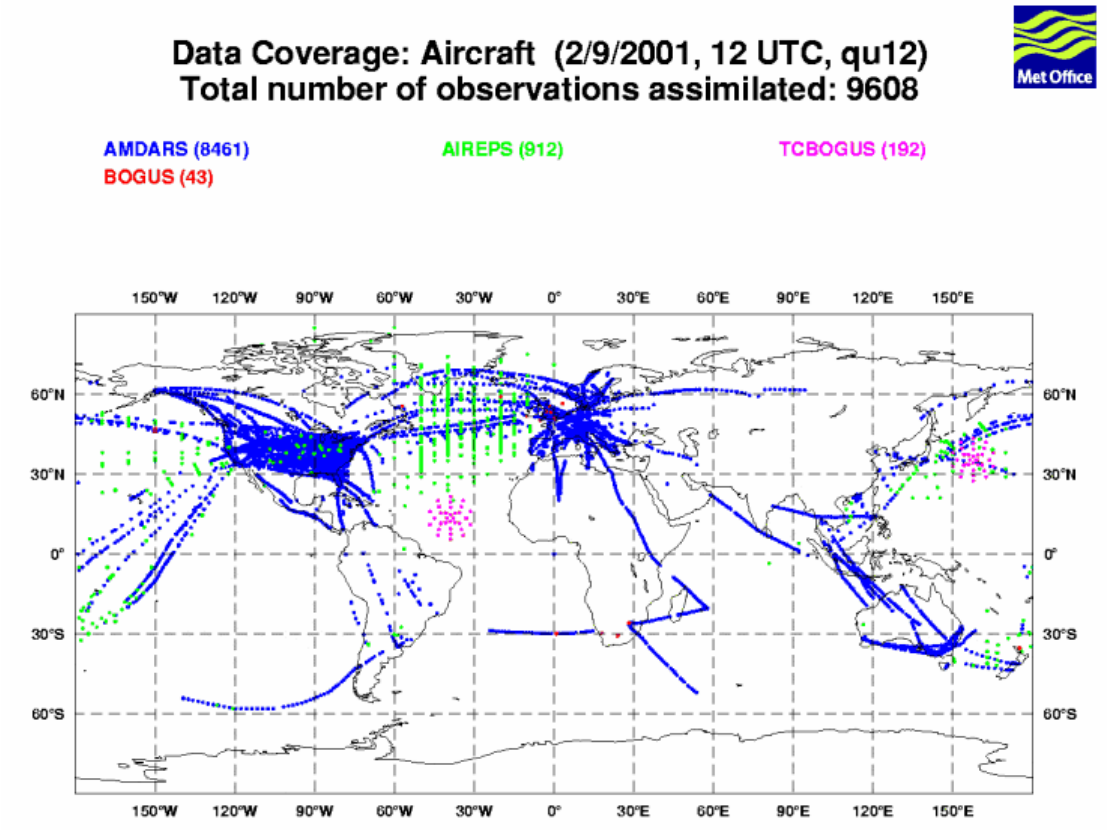


Figure 1(e)

3. Description of the Experiment

The OSE was run using a version of the Met. Office unified forecast model (Cullen, 1993) and 3D-Var data assimilation scheme (Lorenc et al, 2000) using the configuration that was operational in December 2001. In order to reduce the computational expense, the forecast model was run at a reduced horizontal resolution (90 km rather than 60 km) but at the operational vertical resolution of 30 levels. Two one-month periods from different seasons - July 2001 and January 2002 - were chosen in order to sample a large variety of flow regimes. 6-day forecasts were run from the 12 UTC analysis on each day of both periods.

The reference or ALL DATA run used the following observations:

(i) 'in-situ' profile observations of temperature, wind and humidity from TEMP, PILOT, dropsonde and wind profiler reports;
(ii) satellite radiance data from the HIRS/3, AMSU-A, AMSU-B instruments on NOAA-15 and NOAA-16;
(iii) AMVs derived from infrared images produced by GOES 8/10; infrared, water vapour and visible images produced by METEOSAT 5/7; infrared, water vapour and visible images from GMS;
(iv) aircraft wind and temperature observations from AREP, AMDAR and ACAR reports;
(v) surface pressure from SYNOP and drifting buoy reports, surface pressure and wind from ship, moored buoy, rig and platform reports;
(vi) surface wind speed from the SSM/I satellite
(vii) a small number of 'BOGUS' and 'TCBOGUS' data.

Six data denial scenarios were run in which the following observations were removed from the data assimilation system.

1. NO SONDE: 'in-situ' profile observations [(i)].
2. NO STRAD: satellite radiance data [(ii)].
3. NO AMV: AMV data [(iii)].
4. NO SAT: satellite data in the NO STRAD and NO AMV runs and SSM/I winds [(ii), (iii), (vi)].
5. NO AIRCRAFT: aircraft data [(iv)].
6. NO SURF: observations from the surface network [(v)].

Note also that a small number of 'bogus' data were eliminated in scenarios 1, 5, 6.

For each of these scenarios, sixty forecasts up to 6-days were assessed.

Additional runs investigated the impact of the sub-components of the surface network. These runs used July 2001 data only and thus 30 forecasts up to six-days were assessed. The following observations were eliminated from the data assimilation system.

1. NO SYNOP: SYNOP reports.
2. NO MARINE: observations from surface marine reports (buoys, ships, rigs and platforms).
3. NO SHIP: observations from ships, platforms and rigs.
4. NO BUOY: observations from moored and drifting buoys.

Verification

All the forecasts were verified against both observations (radiosonde and surface) and the analyses from the ALL DATA run. The geographical regions over which the statistics are calculated are defined in Table 1. Since the statistics have been averaged over sixty forecasts from two different times of year, it is expected that the mean statistics estimate the impact of different observing systems on a large variety of different flow regimes. Ideally, OSEs should be run over even more flow regimes covering many seasons but such comprehensive testing was not possible in this experiment due to limited availability of computing resources.

Conclusions from the study were made only if they were based upon impacts that were consistent over forecast parameter, level and forecast range. Since a large number of statistics were examined, for brevity only a representative sample is presented in Section 4.

In order to indicate how the results from OSEs can be influenced by the period chosen and the number of forecasts verified, a comparison of some mean scores from July and January is presented. Also, plots showing the daily fluctuation in scores are shown.

Most of the plots shown can be directly compared with Figures 1-4 in BK2001. Figures 2 & 3 match Figures 1 & 2 in BK2001, and Figures 4 & 5 match Figures 3 & 4 in BK2001.

The results from Observing System Experiments are partly dependent on the period, and its duration, chosen for study. This determines the observations used and the type of flow regime. Thus it should be noted that during the two three-week periods (16/12/98 -> 6/1/99 & 20/9/99 -> 10/10/99) BK2001 used for their study, the GOS was different to the period of the Met Office study. In particular, data from NOAA-16 were not available during the ECMWF experiment. The method of processing of the data and its assimilation into the forecast model also affects the results. The main difference to note here is the use of 4D-Var by ECMWF (Rabier et al, 2000), compared with 3D-Var by the Met Office. It is also worth considering the definition of verification area (see Table 1). Both in this study and the ECMWF experiment verification regions defined by CBS[2] are used except for the verification of height forecasts over Europe. In this case, the 'European' area used by ECMWF is different to that used in this study; the ECMWF (CBS) region extends further east than that used by the Met Office. All these considerations have to be taken into account when attempting to explain specific differences between the two experiments.

[2] CBS - WMO Commission for Basic Systems. WMO list of radiosonde stations for verification.

Northern hemisphere	North of 20°N
Southern hemisphere	South of 20°S
Tropics	Between 20°N and 20°S
Europe	70°N-25°N, 10°W-28°E (for height) 75°N-35°N, 12.5°W-42.5°E (for wind - CBS region)
North America	60°N-25°N, 120°W-75°W
Asia	80°N-25°N, 45°E-170°E

Table 1. Definition of verification areas.

4. **Impact of the Observing Systems**

4.1 Impact of satellite data

The impact of satellite data on height and wind forecasts is shown in Figures 2 & 3. The main points to note are as follows.

- ***Satellite data have a large positive impact on both geopotential height and wind forecasts in the southern hemisphere***. In the southern hemisphere, satellite data improve the skill of geopotential height forecasts by 24-48 hours [Figures 2(c)]. In the tropics the impact is less but greatest on the geopotential height field (18-36 hours) compared with the wind field (up to 18 hours) [Figures 2(b), 3(a) & 3(c)]. In the northern hemisphere, the total impact is much smaller at less than 6 hours for both height and wind forecasts [Figures 2(a) & 3(b)].

- ***The benefit of AMV data can be most clearly seen in the tropics.*** For 850 hPa wind forecasts in the tropics, most of the benefit of satellite data is due to AMV data [Figure 3(a)], although at 200 hPa the impact is neutral [Figure 3(c)]. For forecasts of 500 hPa geopotential height in the tropics, AMV data give a benefit of about 12 hours up to T+72 [Figure 2(b)]. Such positive impacts are not seen in either the northern hemisphere [Figures 2(a) & 3(b)] or southern hemisphere [Figures 2(c) & 3(e)].

- ***The impacts of satellite radiance and AMV are not always additive.*** By comparing the NO SAT and NO STRAD curves in Figure 2(c), it can be deduced that AMV data only have a measurable impact on southern hemisphere forecasts of 500 hPa height if satellite radiance data are not present. A similar result is seen for 500 hPa height forecasts in the tropics where the combined effect of removing all satellite data is greater than removing the observation types individually [Figure 2(b)]. For wind forecasts in the tropics, AMV data have a large impact of about 12 hours when satellite radiance data are not present [Figure 3(c)]. In the southern hemisphere, AMV data have a clear positive impact on wind forecasts at all levels only when satellite radiance data are not present [Fig. 3(e)].

- ***The impact of satellite data over Europe is neutral overall.*** A small impact is seen against both 500 hPa geopotential height [Figures 2(d)] and 850 hPa wind [Figure 3(d)].

The impacts discussed above are largely consistent in the vertical as is illustrated in Figures 2(e) & 3(e), which shows the variation with height in the southern hemisphere. Note that to avoid showing overlapping lines, only the scores for 48-hr, 96-hr and 144-hr forecasts have been plotted in these figures. Also note, that the small negative impact from AMV data seen at 200 hPa in the tropics [Figure 3(c)] is not seen at most other levels (not shown).

Comparison with the ECMWF experiment

Figures 2 & 3 can be compared directly with Figures 1 & 2 in BK2001.

The mean impact of all satellite data on height forecasts in the northern hemisphere, tropics and southern hemisphere is similar in the ECMWF and Met Office experiments. AMV have a similar impact on the geopotential height forecasts in the northern hemisphere, tropics and southern hemisphere at both the Met Office and ECMWF, whereas satellite radiance data appear to have a larger impact in these areas in the Met Office runs. The impact on the height forecasts for Europe is negligible in the Met Office experiment but significant in the ECMWF trial. In the Met Office experiment, a greater impact of satellite data on height forecasts can be seen over North America and Asia (not shown).

For wind forecasts, in contrast with the results from the Met Office experiment, BK2001 show that the impact of AMV data on the ECMWF forecasting system in the tropics is negative at 850 hPa but strongly positive, and more important then radiance data, at 200 hPa. At 850 hPa in the northern hemisphere satellite radiance data and AMV data appear to be equally important in the ECMWF experiment, whereas in the Met Office experiment satellite radiance data account for most of the positive impact. Over Europe at 850 hPa, the ECMWF experiment shows that satellite data have a small positive benefit, whereas in the Met Office run the impact is neutral.

The relatively large impact of satellite radiance data compared with AMV data in the Met Office experiment may be due to the fact that the Met Office experiment used the additional radiance data from NOAA-16 which was not included in the ECMWF experiment.

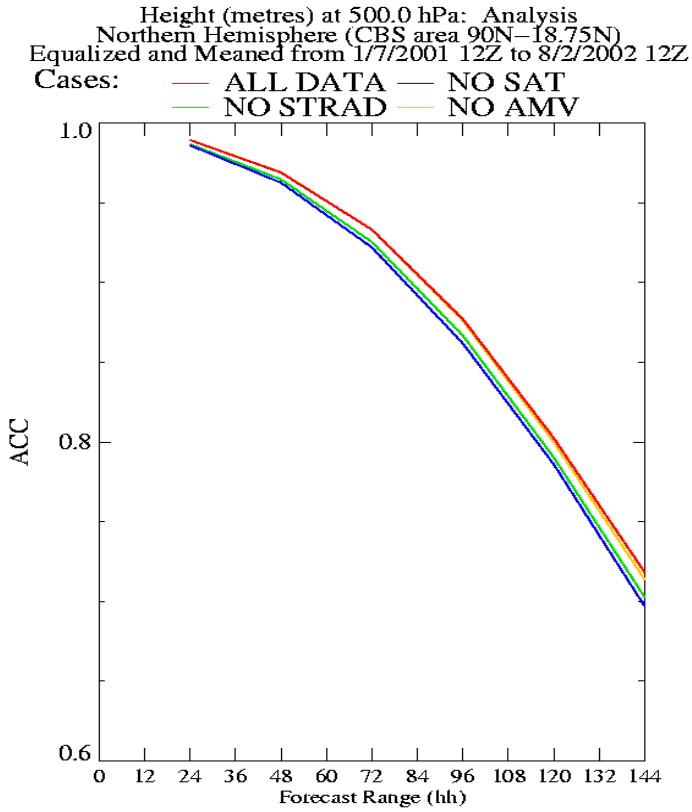


Figure 2(a)

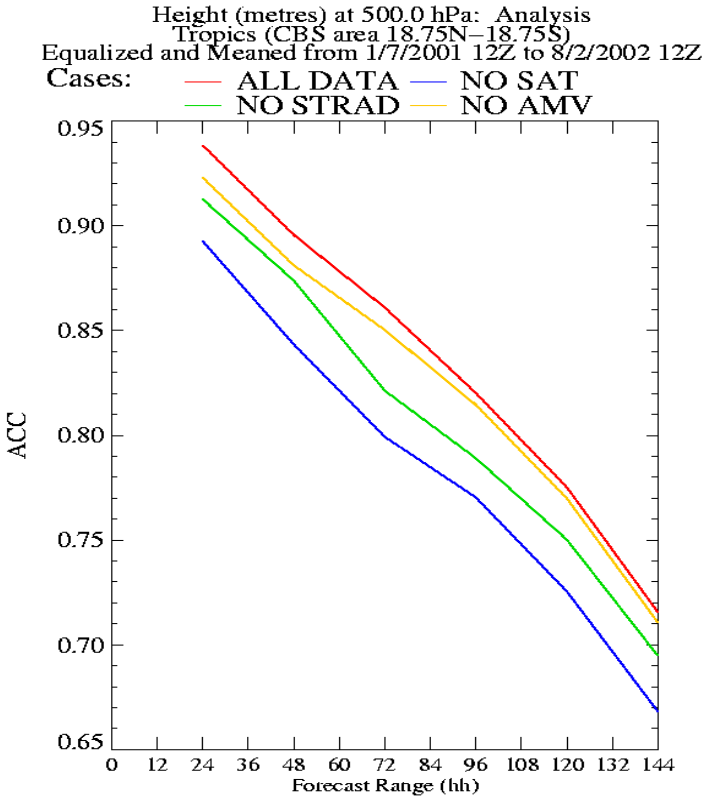
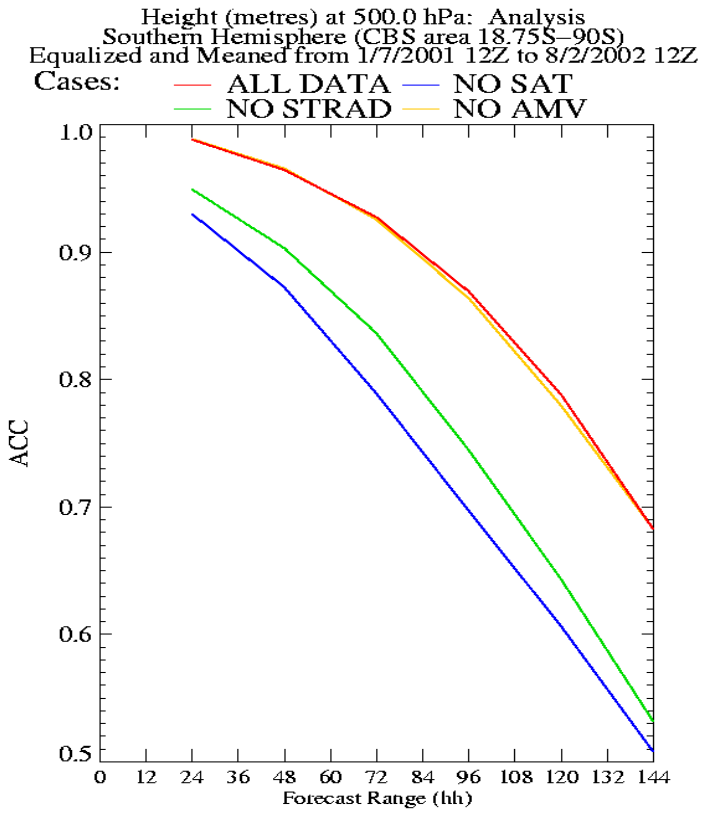


Figure 2(b)



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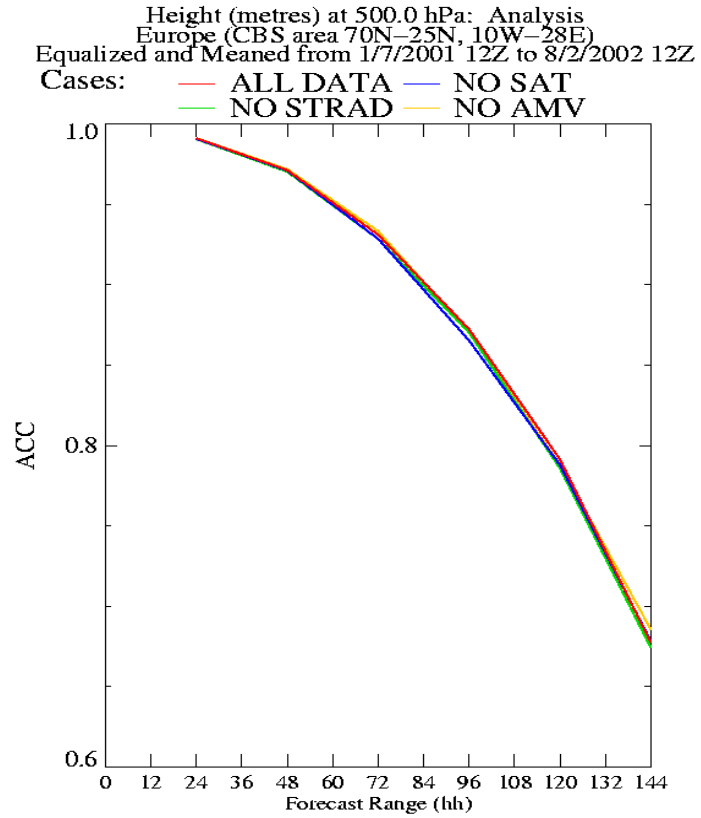


Figure 2(d)

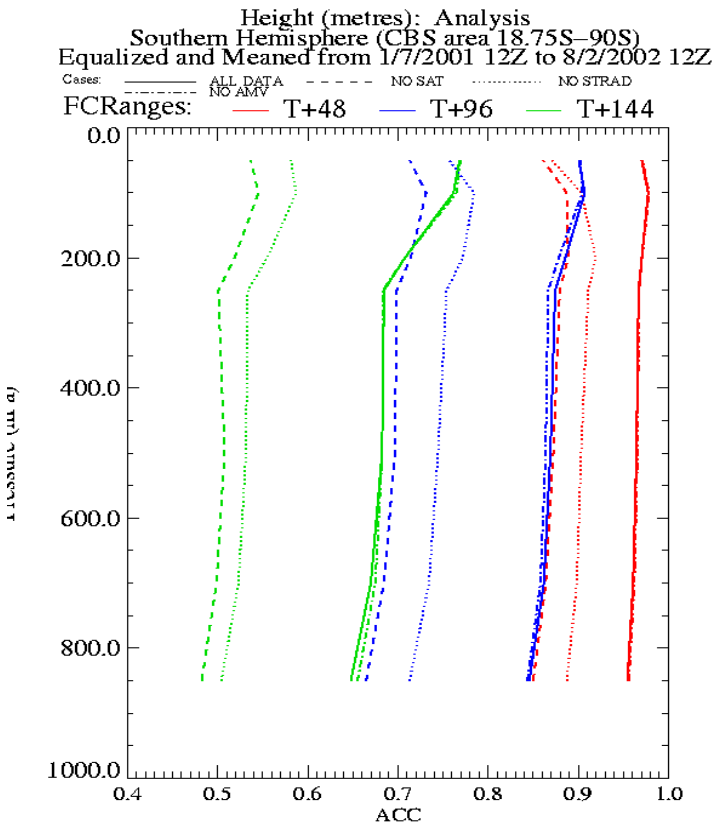


Figure 2(e)

Figure 2. Comparison of satellite data impact. Anomaly correlation coefficient (versus 'All data' analysis):

(a) Northern hemisphere (90N - 18.75N) 500 hPa height
(b) Tropics (18.75N - 18.75S) 500 hPa height
(c) Southern hemisphere (90S - 18.75S) 500 hPa height
(d) Europe (25N - 70N, 10W - 28E) 500 hPa height
(e) Southern hemisphere versus pressure level

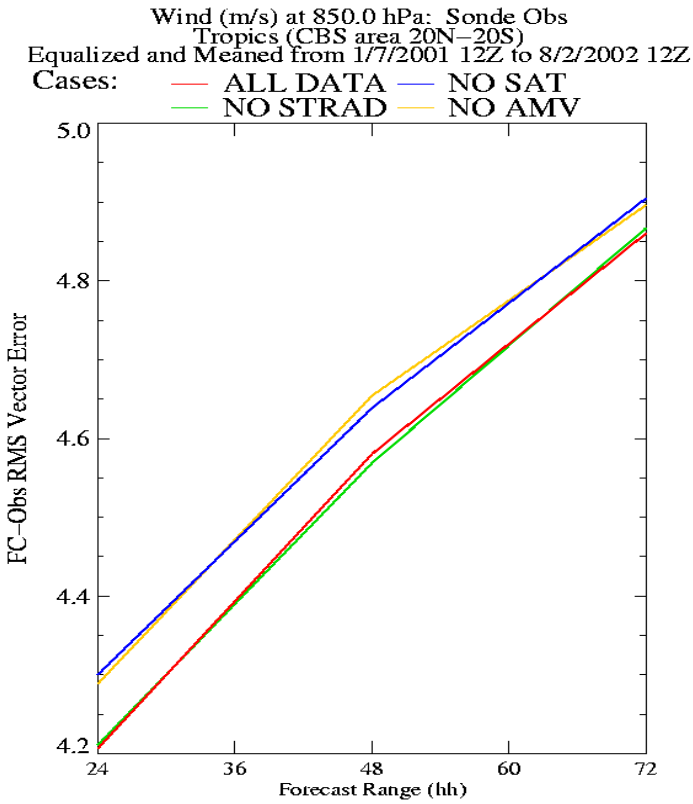
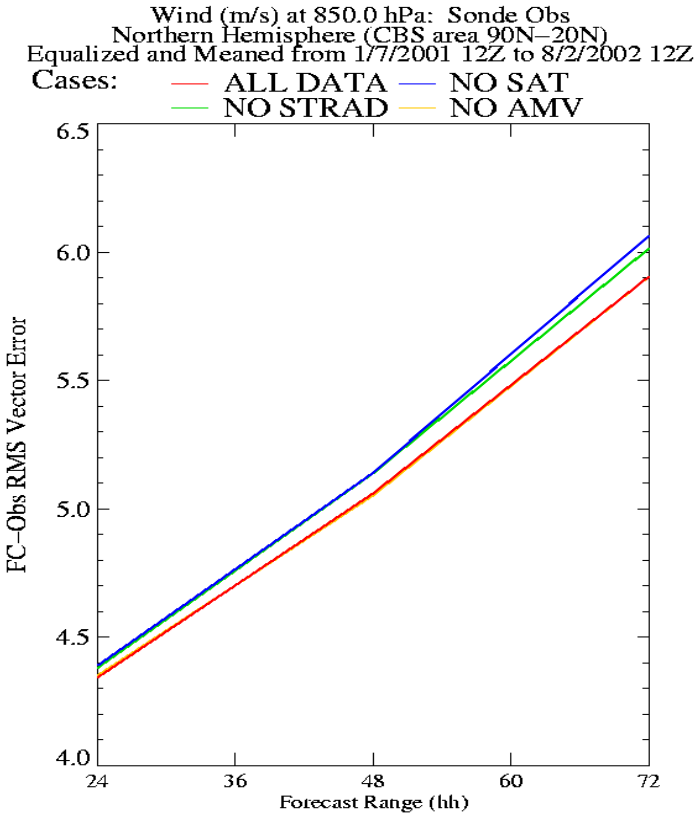


Figure 3(a)



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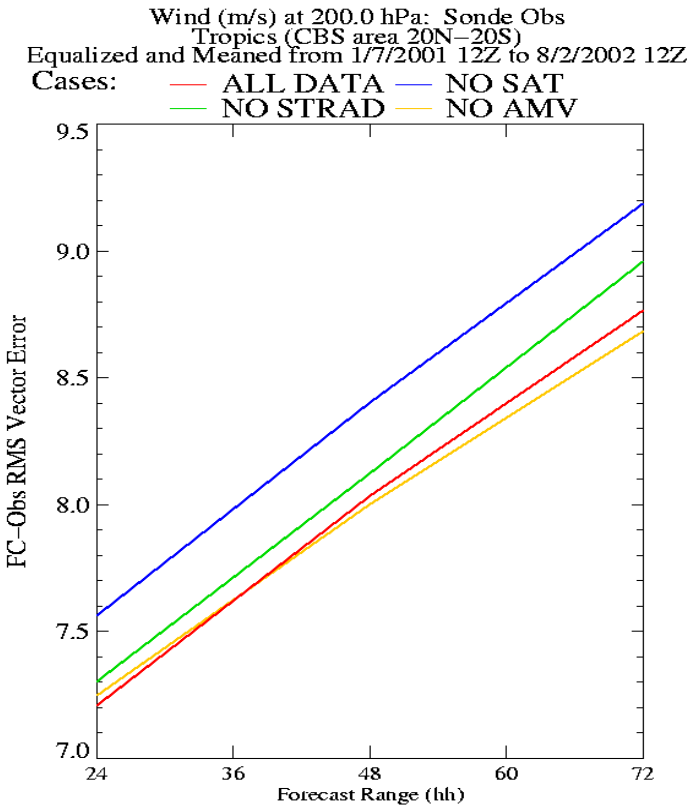

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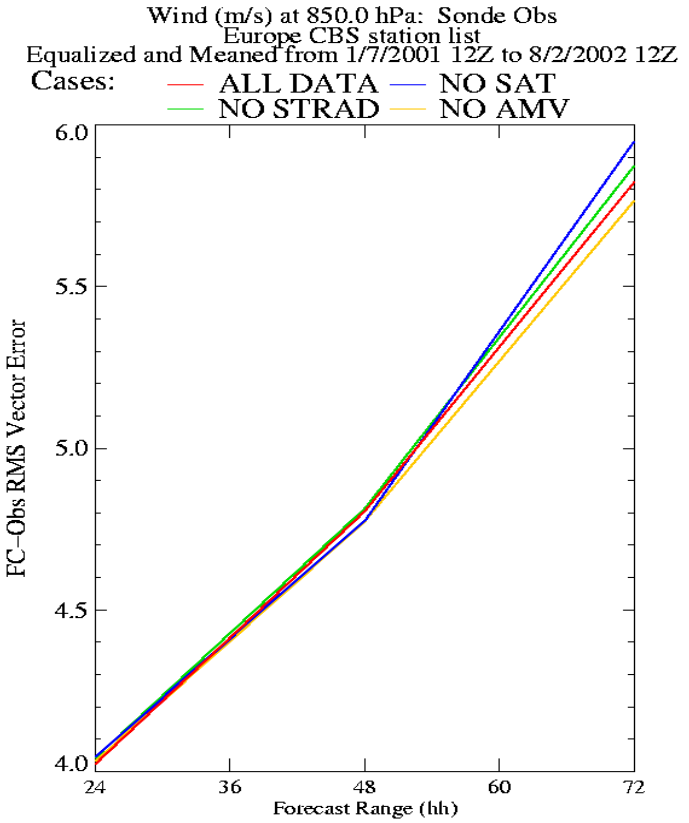


Figure 3(d)

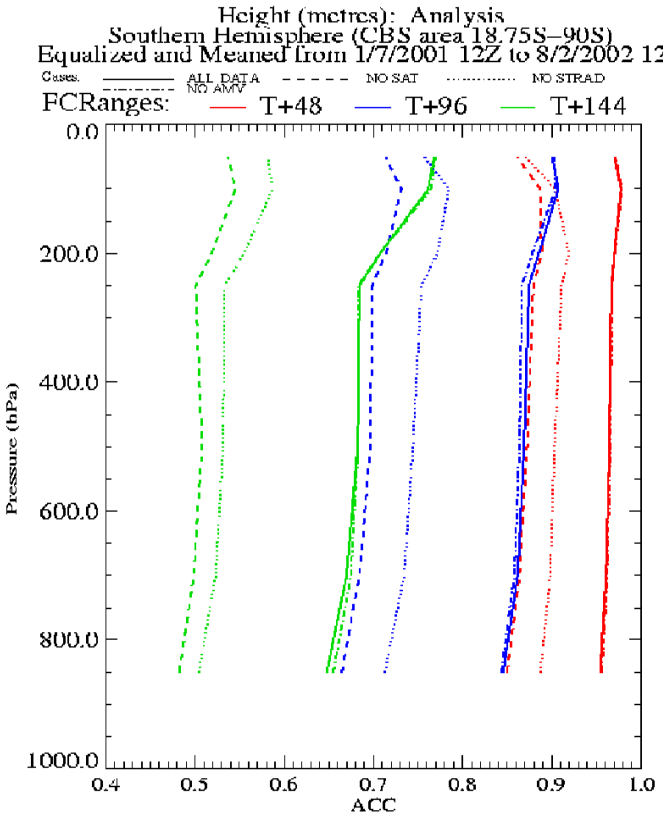


Figure 3(e)

Figure 3. Comparison of satellite data impact for wind. RMS vector wind errors versus radiosondes.
(a) Tropics for 850 hPa wind
(b) Northern hemisphere for 850 hPa wind
(c) Tropics for 200 hPa wind
(d) Versus Europe CBS station list for 850 hPa wind
(e) Southern hemisphere versus pressure level

4.2 **Impact of satellite data vs 'in-situ' data**

The impact of satellite observations is compared with the impact of surface-based observations in Figures 4 & 5. The plots shown are the same as those in BK2001, Figures 3 & 4. Results showing the impact of surface data have been excluded from this section and will be discussed in section 4.3.

The main points to note are as follows.

- ***Radiosonde data have a large positive impact overall on forecasts of wind and geopotential height in the northern hemisphere.*** For example, for 500 hPa geopotential height forecasts in the northern hemisphere, radiosonde data are the most important data source, followed by satellite data and aircraft data [Figure 4(a)]. For 500 hPa wind forecasts over Asia, radiosonde data give a benefit of about 24 hours whereas the other observation types have neutral impact [(Figure

5(d)]. For 500 hPa wind forecasts over North America, radiosonde data have the largest impact of up to 12 hours [Figure 5(b)].

- ***Satellite data have the largest positive impact on forecasts of wind and geopotential height in the southern hemisphere.*** For 500 hPa geopotential height forecasts in the southern hemisphere, satellite data have by far the largest impact of all observation types; the impact at all forecast ranges up to T+144 is about 40 hours [Figure 4(c)]. A similar large impact is seen on wind forecasts (not shown).

- ***Satellite and radiosonde data have a marked positive impact on wind forecasts in the tropics.*** For wind forecasts at 500 hPa in the tropics, radiosonde data have the largest impact up to T+72 [Figure 5(c)] but at longer forecast ranges and other levels, satellite data have the largest impact (not shown). Note that the impact of radiosonde data on short range wind forecasts in the tropics appears larger than in regions of the northern hemisphere [Figures 5(a), 5(b), 5(d)]. Since there is little alternative 'in-situ' profile data in the tropics, the removal of tropical radiosondes from the analysis (and thus short range forecast) is likely to have a large impact and this impact will be clearly measured using verification against the radiosondes that have been removed. In the northern hemisphere, with its abundance of aircraft profile data, analyses and short range forecasts are likely to be less affected by the removal of radiosondes.

- ***Aircraft data have a positive impact on short-range wind forecasts in the northern hemisphere and tropics.*** For 500 hPa wind forecasts over Europe, aircraft data have an impact of up to 6 hours over the forecast ranges 24-72 hours compared with radiosonde data which have the largest impact of all observation types of up to 12 hours [Figure 5(a)]. For 500 hPa wind forecasts in the tropics, aircraft data have an impact of about 6 hours up to T+48 and a smaller impact at longer forecast ranges [Figure 5(c)].

- ***For forecasts over Europe, all observation types have an approximately neutral or small positive impact on geopotential height forecasts, but radiosonde, aircraft and to a lesser extent satellite data, have a positive impact on wind forecasts.*** The mean impact of all observing systems on 500 hPa height over Europe is shown in Figure 4(d). It can be seen that the overall impact of any observing system is approximately neutral. However, radiosonde data and to a lesser extent aircraft and satellite data, have a clear benefit on 500 hPa wind forecasts [Figure 5(a)].

- ***The impact of individual observing systems in the northern hemisphere is small.*** The impact of removing any one observing system is small. For example, for 500 hPa height forecasts, a maximum impact of less than 12 hours on 500 hPa height is seen when radiosonde data are removed [Figure 4(a)]. A maximum impact of about 18 hours on root mean square vector wind errors versus radiosondes was seen at 200 hPa (not shown).

Comparison with the ECMWF experiment

Figures 4 & 5 can be compared directly with Figures 3 & 4 in BK2001.

The impact of radiosonde and satellite data on 500 hPa height over the northern hemisphere is similar in BK2001, whereas radiosonde data have a larger impact in the Met Office experiment. For the same verification score meaned over the tropics, the results are similar although the Met Office experiment shows a larger impact from aircraft data at short forecast ranges [Figure 4(b)]. In the southern hemisphere the impacts are similar for satellite and radiosonde data, but the ECMWF experiment shows a larger impact from aircraft data than in the Met Office experiment [Figure 4(c)]. Over Europe, the ECMWF experiment shows a clear impact from all data types, whereas in the Met Office experiment the impact of all types is neutral [Figure 4(d)].

The impact of all data types on 500 hPa wind forecasts verified against European radiosondes is very similar in both experiments; radiosonde data have the largest impact followed by aircraft and satellite data [Figure 5(a)]. Verified against North American radiosondes, the relative impacts are different. In the Met Office experiment, radiosonde data have the largest impact followed by satellite and aircraft [Figure 5(b)]. In the ECMWF experiment, radiosondes also have the largest impact, but aircraft data have a larger impact than satellite data. For forecasts over the tropics, aircraft data have a larger relative impact in short range (up to 48 hours) in the Met Office run; otherwise the results are similar [Figure 5(c)]. Over Asia, the relative impacts are very similar in the two experiments [Figure 5(d)].

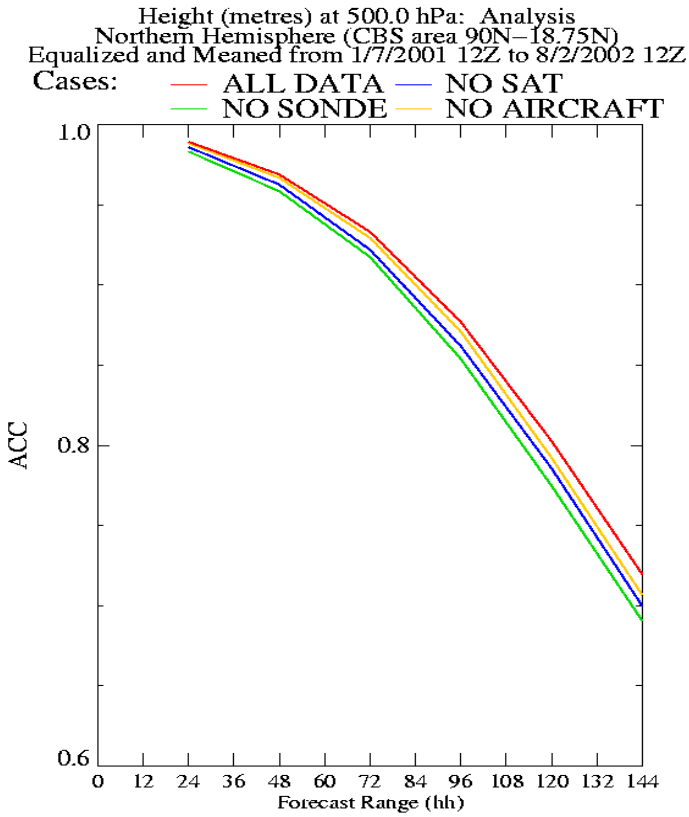
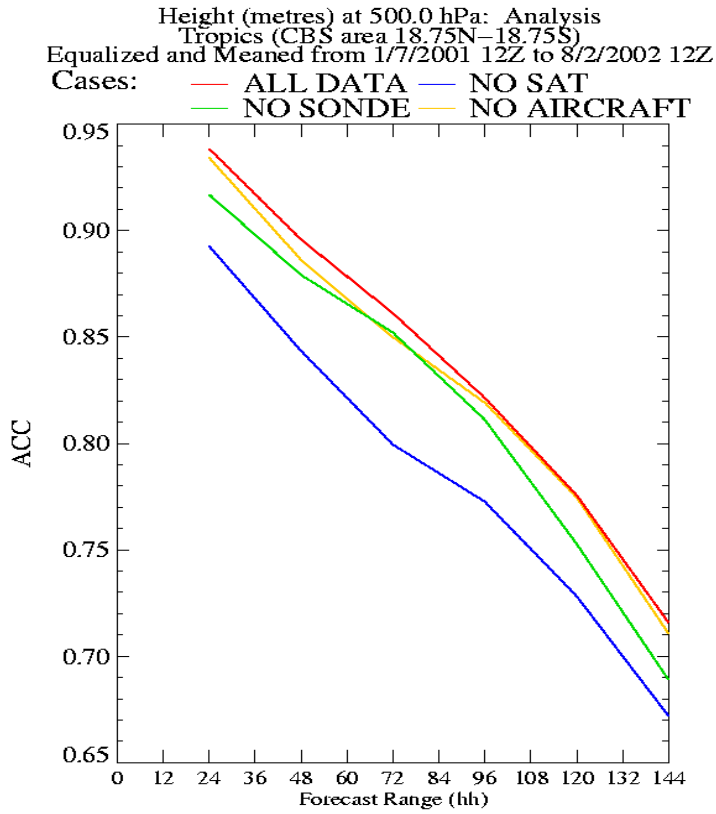


Figure 4(a)



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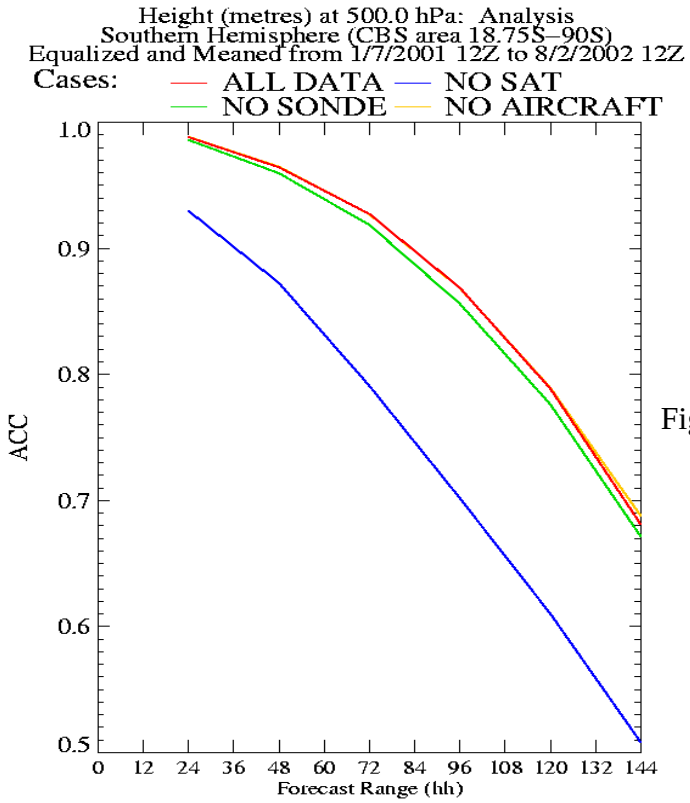


Figure 4(c)

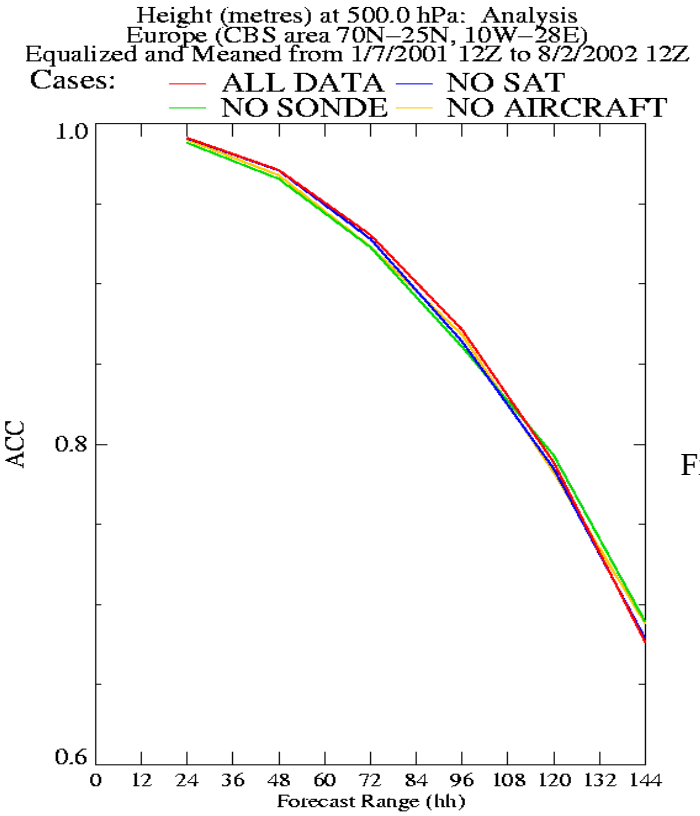


Figure 4(d)

Figure 4. Comparison of satellite and surface-based data. 500 hPa height anomaly correlation coefficient for (a) Northern hemisphere (b) Tropics (c) Southern hemisphere (d) Europe.

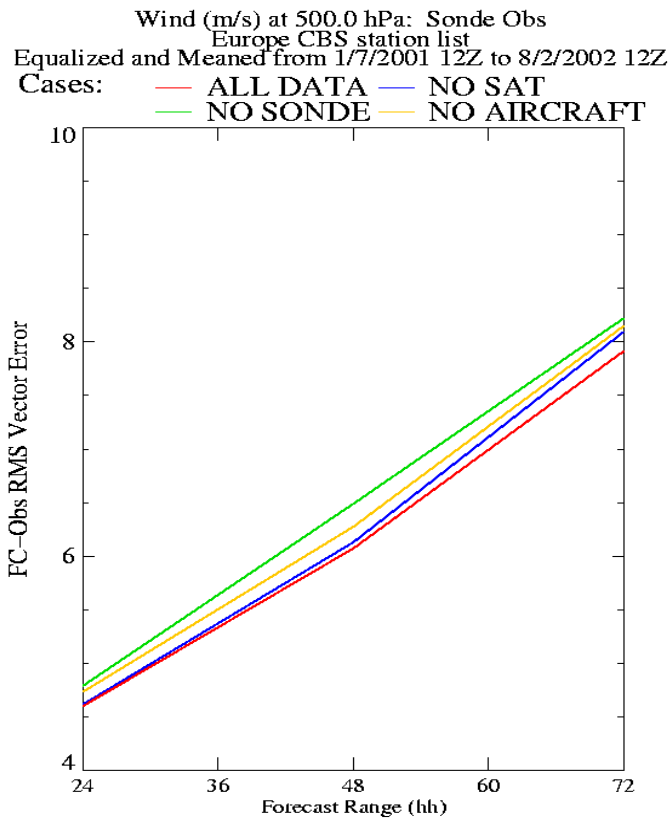


Figure 5(a)

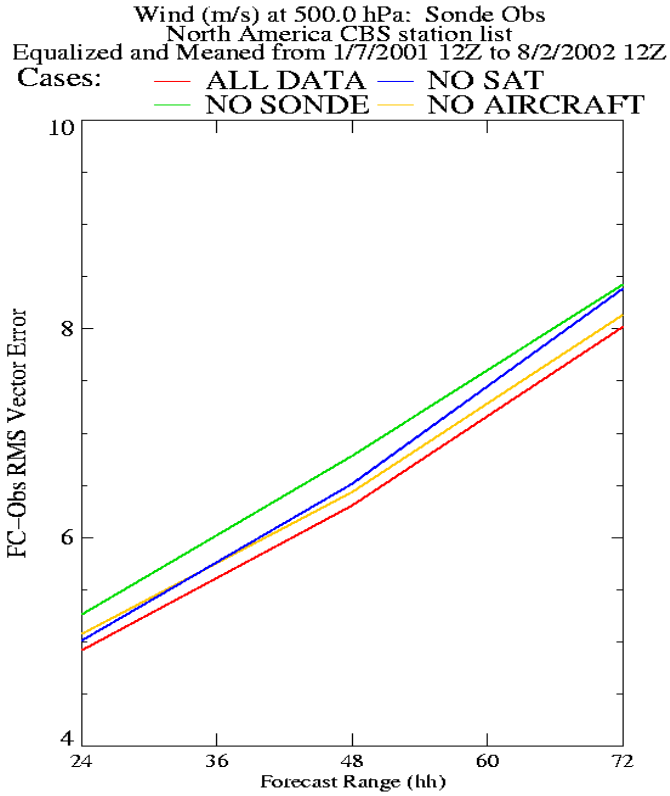


Figure 5(b)

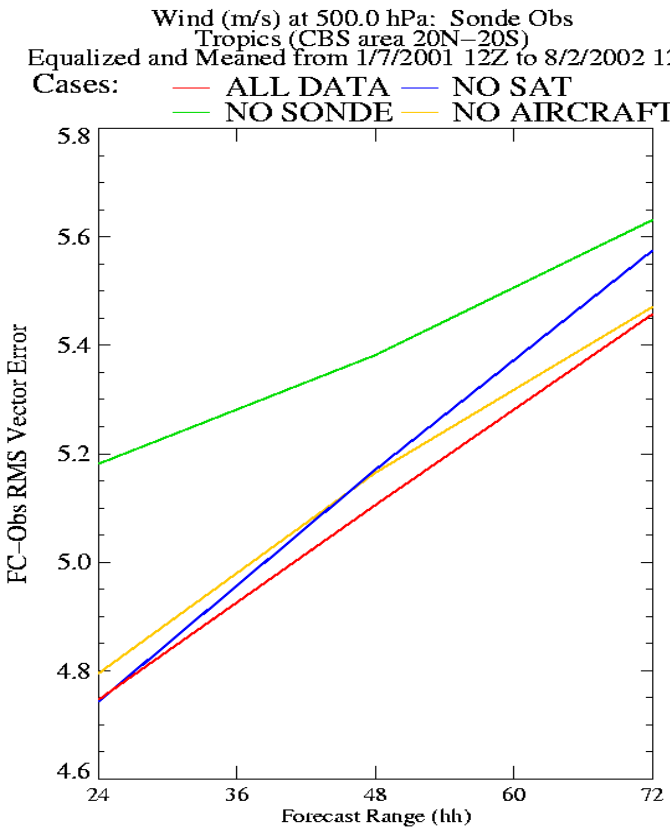


Figure 5(c)

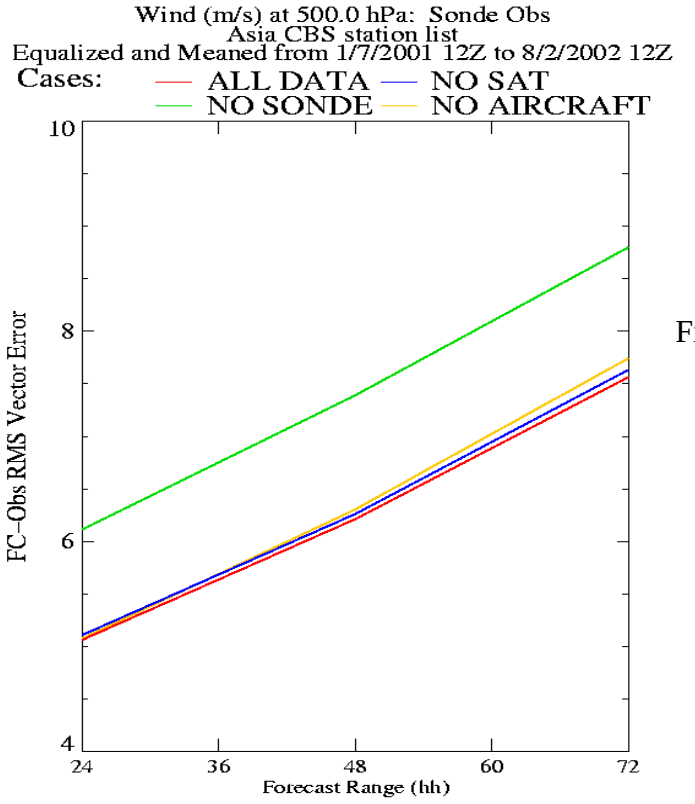


Figure 5(d)

Figure 5. Comparison of satellite and surface-based data. Root mean square vector wind error for 500 hPa wind versus radiosondes for (a) Europe (b) North America (c) Tropics (d) Asia.

4.3 **Impact of surface data**

Some results showing in more detail the impact of surface data and components of the surface observing network are presented in this section. Note that the mean scores plotted are averaged over 30 forecasts from July 2002 observations (not 60 forecasts as in Sections 4.1 and 4.2). The Met Office global data assimilation system uses surface pressure from all surface reports; surface wind observations from ships, moored buoys, platforms and rigs; no surface temperature observations are used.

From Figure 6(a) it can be seen that surface data have a large impact on forecasts of mean sea level pressure. Similar results exist for the tropics and southern hemisphere, but are not shown here. It is thus concluded that 'in-situ' surface pressure observations are essential for Met Office forecasts. It appears that the data assimilation scheme cannot produce a good surface pressure field using upper air observations only.

From Figure 6(a) it can also be seen that removing whole sub-components of the surface network makes very little difference to the mean scores, except for forecasts up to T+24 in the case when all SYNOP reports are removed. This result suggests that whilst some 'in-situ' surface pressure observations are essential, the Met Office global NWP system run at 90 km resolution does not need a dense network [as indicated in Figure 1(a)].

Surface observations have a large positive impact on 500 hPa geopotential height, when verifying against radiosonde observations, as indicated in Figure 6(b). The impact on the geopotential height field is largely due to changes in the surface pressure field; the upper level temperature fields are not affected significantly by removing surface observations [Figure 6(c)].

Verification against observations reveals a much larger impact from surface data on height forecasts than can be seen using anomaly correlation coefficient scores (not shown). A major component of the RMS error that occurs when surface data are denied is due to a systematic loss of model pressure [Figure 6(d)]. Root mean square forecast errors for height verified against the ALL DATA analysis (not shown) show a similar large error suggesting that the errors may have a wide geographical distribution. A particular example of the error introduced into the surface pressure field when surface data are denied is given in Figure 6(e). Although the main meteorological features are in similar positions on both maps, close inspection reveals that in the NO SURF run the pressures are reduced by around 4 -6 hPa. Given small positional errors, it appears that a systematic amplitude error of this magnitude is not clearly measured by the anomaly correlation coefficient.

The relative importance of the surface network on the 24-hour forecast of mean sea level pressure is indicated in Figure 6(f). Clearly surface observations have a much larger impact than any other observing system. Consequently, the impact of surface data on the verification of height forecasts versus observations is greater than any other observing system.

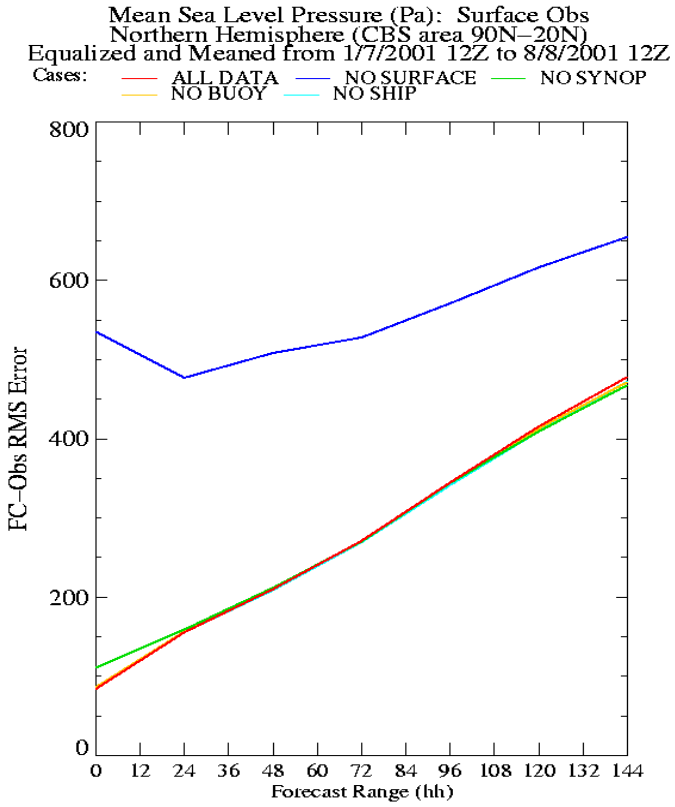


Figure 6(a)

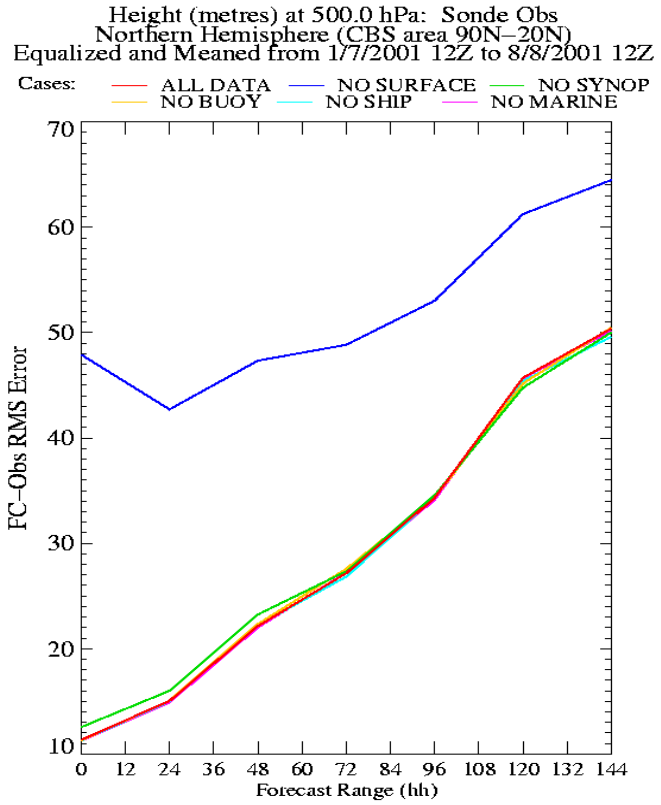


Figure 6(b)

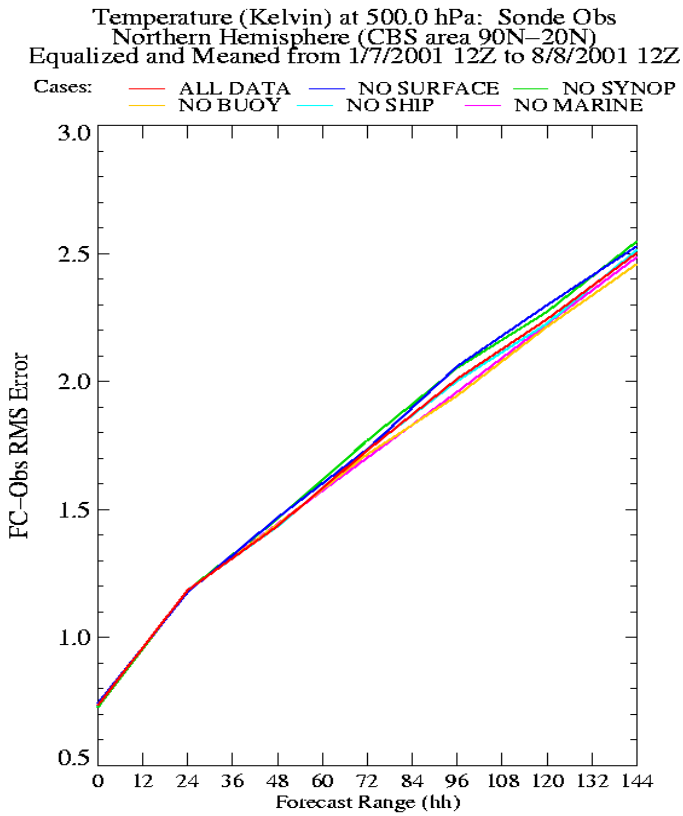


Figure 6(c)

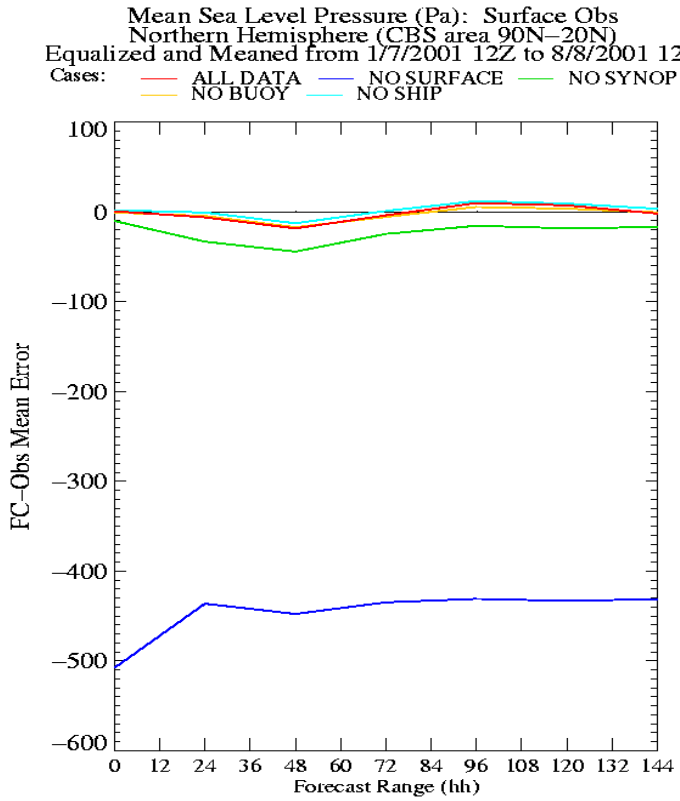
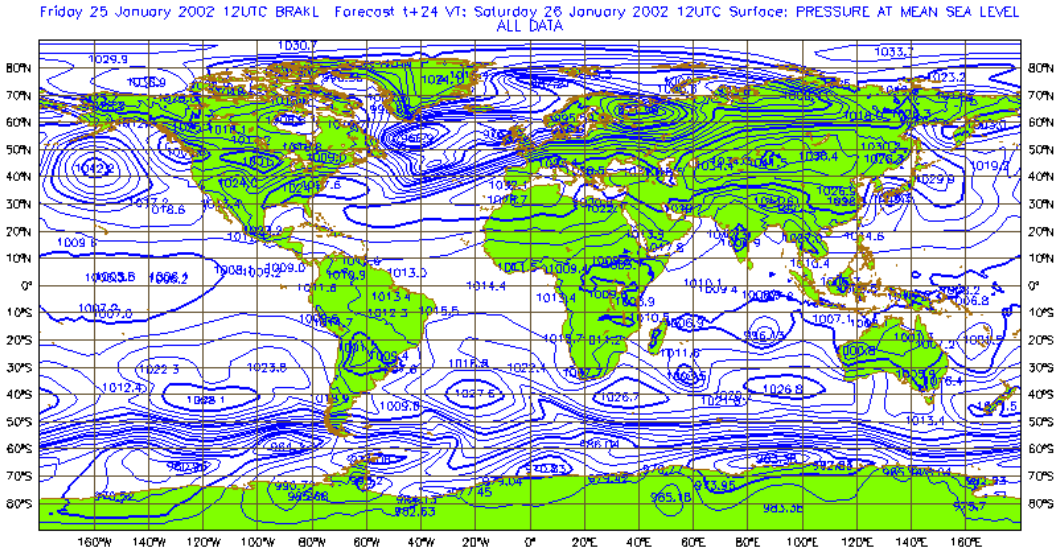
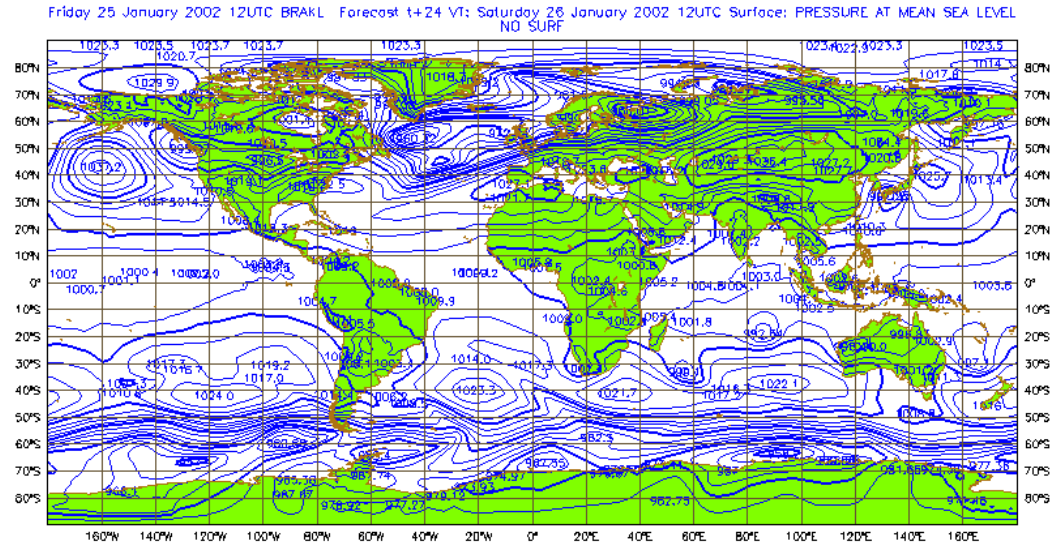


Figure 6(d)



(i)



(ii)

Figure 6(e)

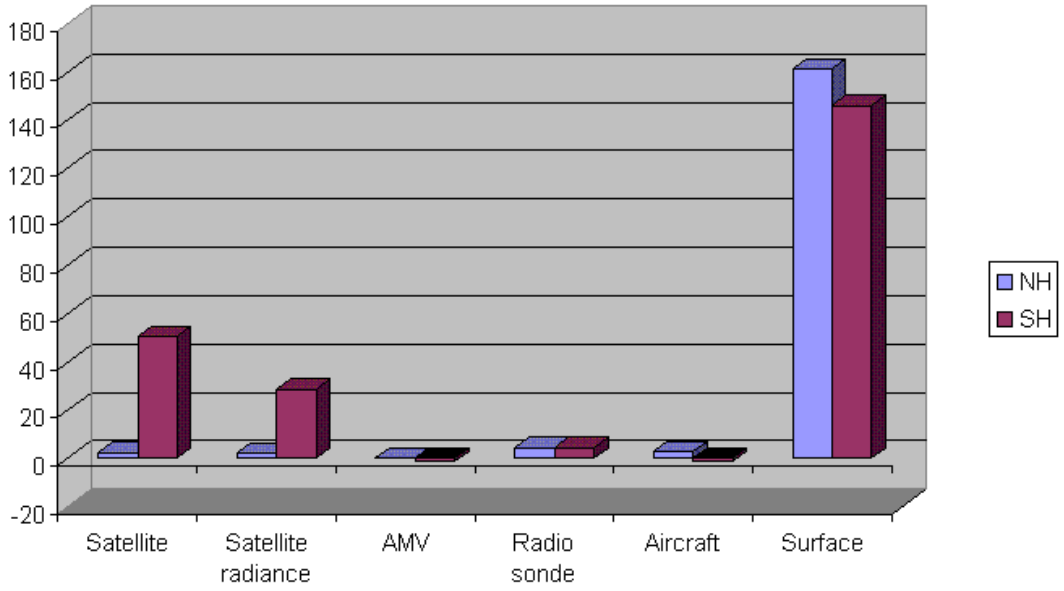


Figure 6(f)

Figure 6. Impact of surface observations. Root mean square errors versus observations meaned over the northern hemisphere for (a) mean sea level pressure (b) 500 hPa geopotential height (c) 500 hPa temperature. (d) Average mean sea level pressure error (e) 24-hr forecast of mean sea level pressure from 12 UTC 25/1/02 from (i) the ALL DATA run (ii) the NO SURF run. (f) Percentage change in RMS error of 24-hr forecast of mean sea level meaned over the northern and southern hemisphere for all observation types.

4.4 **Influence of sample size and period**

Figures 7(a) & 7(b) show the differences in the impacts of satellite and surface-based observing systems on 500 hPa height. Both figures show the mean impact on the anomaly correlation coefficient over 30 forecasts. The values in Figure 7(a) were calculated from July 2001 forecasts and those in Figure 7(b) from January 2002 forecasts. It can be seen from the figures that satellite data have the largest impact on forecasts in July whereas radiosonde data have the biggest impact in January. Since the same NWP system was used to produce the forecasts from both periods, the differences in the results must either be due to differences in the observation coverage or flow regimes. It was shown in Section 4.1 that most of the impact of satellite data in the northern hemisphere is due to the satellite radiance measurements from NOAA-15 and NOAA-16. Table 2 shows that the total number of satellite radiance profiles from these satellites and the number of radiosonde soundings. It can be seen that the number of satellite radiance and radiosonde data from each period was similar. Assuming that the distribution of the observations was also similar, then the differences in the results are likely to be due to the flow regime.

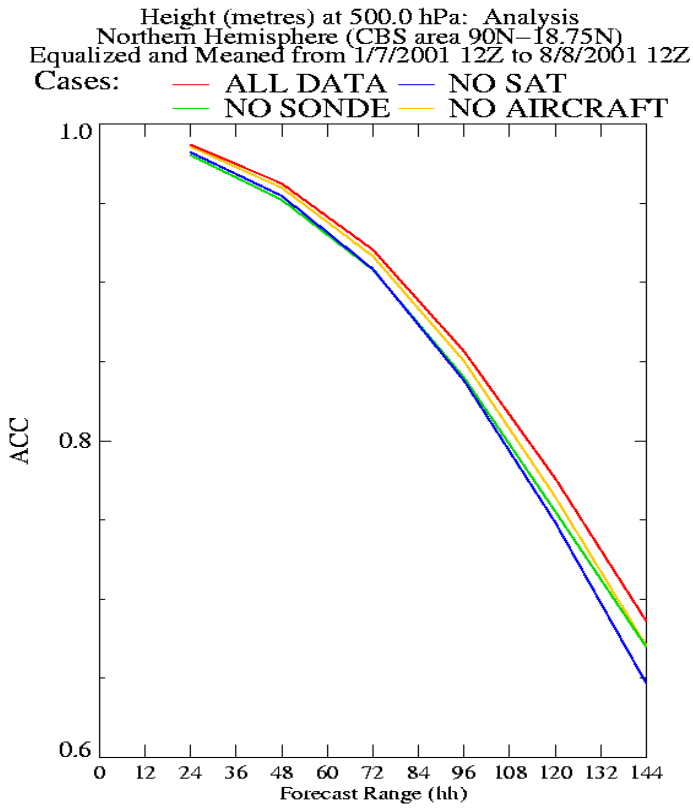


Figure 7(a). Mean 500 hPa height anomaly correlation coefficient for northern hemisphere. Mean taken over 30 forecasts from July 2001.

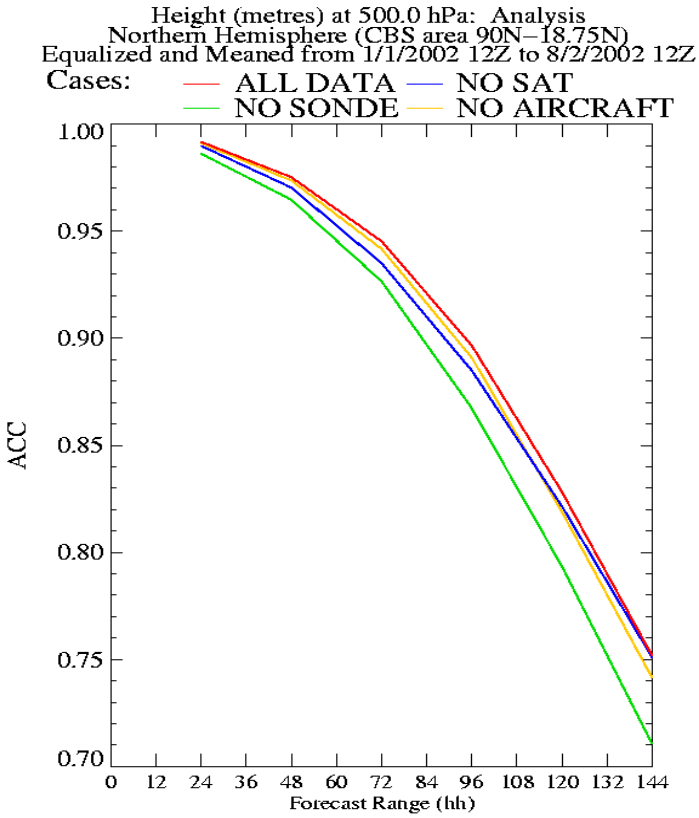


Figure 7(b). As Figure 7(a) but for January 2002.

	Radiosonde	Satellite (NOAA-15 & 16)
July 2001	63,965	38,138,928
January 2002	64,751	39,718,936

Table 2. Total (global) number of radiosonde and satellite radiance data available for assimilation.

Figure 7(c) shows an example of the daily fluctuation in 500 hPa RMS vector wind errors over Europe during July 2001. This Figure should be compared with Figure 5(a) which shows the mean impact. It can be seen from Figure 7(c) that the impact of satellite data is sometimes positive and sometimes negative, although Figure 5(a) shows that the mean impact is positive. Figure 7(c) shows how verifying small numbers of forecasts can give misleading results. The forecasts verifying between 7th and 14th July indicate a negative impact from satellite data, whereas those verifying between 23rd July and 6th August indicate a mainly positive impact. It should be noted that the mean RMS error for this period may be strongly influenced by the error of the forecast verifying on 17th July - the presence of satellite data for this forecast appears to have had a large positive impact.

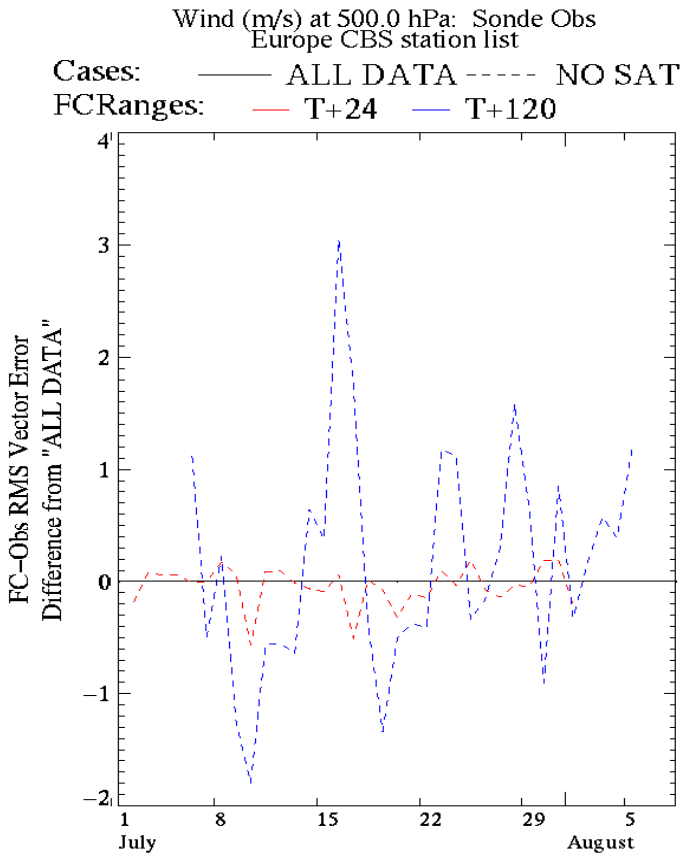


Figure 7(c). Difference (NO SAT-ALL DATA) in 500 hPa RMS vector wind errors verified against European radiosondes for 24-hr and 120-hr forecasts in July 2001.

5. Summary and conclusions

The results presented show that overall all observing systems are having a positive impact on Met Office forecasts. Thus the Met Office 3D-VAR data assimilation system performs well. Satellite data have the largest impact of all observing systems in the southern hemisphere, with satellite radiance data having a larger impact than AMV data. Radiosonde data have an important impact, particularly in the northern hemisphere. These points are illustrated in Figure 8 which shows the impact of all observing systems on the root mean square vector wind error for 24-hr forecasts of 250 hPa wind.

Surface data are crucial for providing realistic forecasts of surface pressure; the Met Office data assimilation and forecast system cannot produce accurate surface pressure forecasts using upper air data alone.

Care is required when interpreting the results from these OSEs. It has been shown here that the results depend on the period chosen for study and its duration.

The results are in broad agreement to those of a similar study carried out at ECMWF. The reasons for differences cannot be easily identified using the results of this Met Office study but are likely to be due to differences in the periods chosen, in terms

both of flow regime and observation availability, and the data assimilation methods employed.

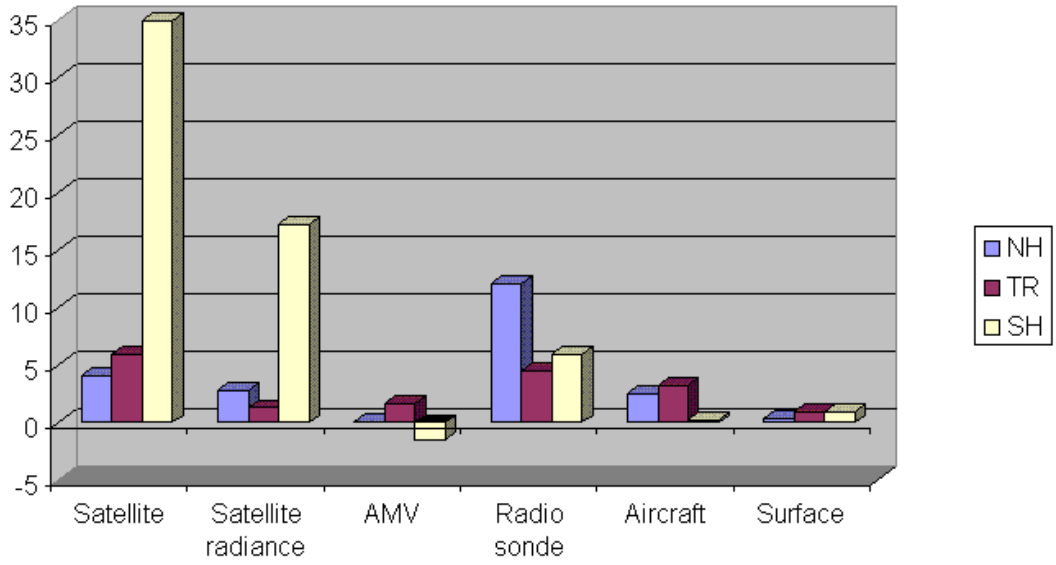


Figure 8. Percentage change in RMS errors (vs observations) for 24-hr forecasts of 250 hPa wind

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